Economics of Electric Energy Delivery

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Gentlemen, it's a distinct pleasure to be asked to talk to you today on the transport and storage of electric energy. We've taken the liberty of calling our discussion the "Economics of Electric Energy Delivery," and you'll note soon that one of the hallmarks of this talk is its inability to stick to the subject.

It is plain from the program that the role of our paper is to take over the discussion of energy from the point where this energy has been converted to electricity, and to see it delivered onto the premises of the ultimate consumer. If, on the way, this energy can be stored for a few hours, we're supposed to discuss that too.

In its simplest form, then, the discussion would concentrate on what the electric utility engineer calls the "T and D" system -- meaning, of course, the transmission and distribution system. And since the popularity of pumped storage, at least in the U. S., has recently zoomed upward, we could then discuss pumped storage as the ultimate in techniques for "storing electric energy" enroute from the conventional generating station to the customer.

Unfortunately for simplicity, but fortunately for power system planners who make a living because the subject is <u>not</u> simple, it is extremely difficult to divorce the subject of the transmission and distribution of electric energy from the subject of its generation. The economics of all three are indelibly and irrevocably intertwined, although, surprisingly, the subject of distribution can stand on its own feet without the other two much easier than can generation or transmission.

Before we get confused prematurely, let's start by defining a few terms in the jargon, and from the viewpoint of the electric power system operator. Let's pick out just five: generation, transmission, distribution, storage and interconnection.

The term "generation" is probably self explanatory. It means the facilities to convert energy from stored or flowing water, or from fossil fuels, or from the atom, to electricity. Generally, generation is accomplished, for economic and technical reasons, at voltages of about ten to twenty-five kilovolts. We'll later see that this voltage range is about identical to the range of primary voltages in the distribution system, so that in some cases it is possible to feed power at generated voltages directly into the primary mains for distribution. In fact, in the early power systems, this was the general rule. But economics and the geographical separation between the typical power plant location and that of the load center now decree otherwise in the usual case. So we come to our next definition.

The term "transmission" conventionally means the facilities to move the electric energy from the generating plants to bulk receiving points, and from the bulk receiving points to local distributing points. The bulk receiving points generally are called "transmission substations," and the local distributing points "distribution substations," and both types are located with economic finesse throughout the system.

The transmission lines tying generating stations to bulk receiving stations are generally regarded as the transmission system. They usually operate at voltages of 115,000 volts and up to 345,000 volts at the present time in order to minimize transmission losses by holding down current flow, and in order to pack maximum energy transport capability into minimum right of way real estate.

The network of lines tying bulk substations to distribution substations is often called the "subtransmission" system, and they may operate at voltages from 230,000 volts down to around 20,000. Very large customers may be served from the subtransmission system. The distinction is made between "transmission" and "subtransmission" according to the role they play in the power system, and not by the voltage level, which varies from system to system.

The distribution system is fed from the distribution substations, and it may operate from 26,000 volts down to about 4,000 volts. The distribution system may be radial when the individual feeders are not connected together, and the loss of which results interruption for the customer supplied from the line, or they may form a network and be fed from several substations. Larger customers and the secondary systems are supplied directly from the distribution system.

When we talk about storage we do not mean storing energy in the form of electricity, as it cannot be done economically in large quantities. We also want to exclude here the economics of fuel storage. The only known economic way to store electric energy enroute from the conventional generating station to the customer is by pumped storage. This technique involves pumping water from a lower reservoir to a higher one during light load time at low production cost in order to release the water at the time of high demand and high production cost. Actually, another indirect form of storage is achieved by a conventional hydro station where the water is retained in the reservoir when the energy is not needed and released only when the demand is high.

Interconnections are simply transmission lines built between two or more neighboring utilities to interchange energy when it is mutually advantageous; that is, when one can produce excess power at a lower cost under normal conditions and for mutual help during emergencies. In case several systems join in an interconnection agreement the group is frequently called a power pool.

While each of these major parts of a power system has its own characteristic economic problems, the economics of the electric energy delivery must be looked at from the standpoint of the whole system. Specific problems, such as transmission and pumped storage, cannot be divorced from economics of operation and expansion of the entire system.

We will first briefly talk about the economics of producing power and expanding a system in general, then will go into detail of the economics of transmission.

Figure 1 shows the invested capital structure of a typical power company. Power plants take the largest share, but distribution facilities take almost as much. Transmission takes a smaller share and the "others" category includes items like buildings, shops, vehicles, etc. This relative distribution, of course, may vary from company to company depending on the location and density of load, but it is quite representative of the industry as a whole.

Economic Operation of a power system

A power system in existence, with the facilities then available for service, must be operated with maximum economy. Further, the system must be expanded in the most economic manner to meet future loads. These two problems are not really separable because, in planning the economic expansion of a system, the operating characteristics of the future system is very important. Setting down the operating principles is, therefore, logical and necessary to form the basis for further discussion of the problem.

Load Characteristics

Before we can talk about the operation of a system, it is necessary to discuss the unique load characteristics of a power system. Many basic economic problems are the direct result of these characteristics. Figure 2 shows typical daily load characteristics of a power system. The chart shows the load for a normal winter weekday.

The shape of the curve may change from season to season, as temperature and the daylight hours vary. Basically, the load has a minimum value below which the load never descends, sharply increasing periods and peak loads lasting only a few hours a day, followed by rapidly decreasing periods. The power generated by the system every moment must be equal to the demand, as energy cannot be stored economically in the form of electricity. The generating equipment available to meet the load usually varies in size, efficiency, reliability, and cost of fuel, etc., some located near load centers, some at far away hydro plants or minemouth generation sites. Spinning reserve must be available to cover the possibility of the sudden outage of some equipment and additional reserve capacity must be built to allow scheduled and non-scheduled maintenance.

To achieve minimum cost of energy delivery at all times, it is necessary to schedule the available generating units carefully throughout the day. The high efficiency units, which are characteristically the newer and larger size units and which characteristically burn the lowest cost fuels, are therefore utilized to provide as many kilowatt hours as possible and practicable. These units are assigned to carry the so-called "base load", and usually are not taken out of service except when maintenance is required. Less efficient units are assigned the next block of load and these may be taken out of service every night, except certain ones which may be kept on line for local area protection in case of transmission failure. Non base-load units are usually older units once themselves serving as base load units.

The peak load hours frequently are taken care of by so-called peaking units, which may be relatively low efficiency internal combustion units (diesel or gas turbine) or "bare bone" low efficiency steam units. Conventional hydro plants can be used for any of these purposes depending upon the characteristics of the available water and the storage. Usually the power system is interconnected to a neighboring system and can interchange energy to take advantage of the possible cost differences at any given period, or to provide mutual help in case of emergency.

At any given moment the total delivered energy has a definite cost value which depends upon the combination of cost values of all the generating facilities in service.

The transmission system makes it possible to operate all units in unison and naturally the loading on the transmission lines has some effect on the economics of of the delivery as the losses are higher, if the energy has to be delivered over long distances. The status of the transmission system may affect the whole system economy when uneconomical generation has to be kept in service during the outage of lines or frequently in anticipation of line outages in critical areas. Loading on the lines must be constantly monitored to prevent overloads even by deviating from the economic generation schedules.

The operation of the distribution system is largely independent of the generation system and its daily operation, as it is usually not affected by the loading schedules of the various generators with the exception of some small size peaking units, which may be connected directly to the distribution system. Operating arrangements and outages in the transmission and subtransmission system, however, may affect the distribution system.

Development of an economic power system

Having looked roughly at how an economical power system operates, let us now look into the future and see what basic economic factors govern its expansion. Again we must emphasize that the system as a whole must be considered to achieve the best results.

Let us assume that a reasonable load forecast is available for the entire future period under investigation, not only for the magnitude of the yearly peak load on the whole system, but also the geographic distribution of it, the shape of the load curve and the kilowatt hours to be provided. Variation in this load forecast may materially change the economic expansion pattern, especially as to timing.

The objective of the planning is to develop a schedule of additions to the generation and transmission facilities which assures that the projected load will be met with acceptable reliability and the cost of energy will be minimum in the future. Investment cost of the new equipment, generating and transmission, and the overall operating cost of the entire future system must be carefully analyzed.

Turning to generation expansion problems, there are usually a very large number of alternatives available. The location of new units as related to the existing and projected transmission system is one of the first considerations. The size of the unit has a strong influence on the installation cost, as the cost per kw decreases with the increase in size. The amount of necessary reserve capacity depends upon the size and reliability of the existing and future units. If only a few large size units are built it will be necessary to have more reserve capacity to cover the outage of the large units. This may be detrimental because the extra reserve capacity may cost more than the gain from the large units. The fuels to be used, especially the projected fuel prices at the considered location, may be decisive. The selection of types of units, for example base load versus peaking, is one of the most interesting tasks of a system planner. No universal rules can be set forth, as size of the particular system under consideration, the potential load growth, fuel prices, available hydro, etc., all play decisive influence. One may think, why not build only large efficient units in the future to take advantage of the decreasing installation cost. If we note that the load on the system is such that the peak demand lasts only for a short period, it is obvious that the large units will not be loaded up always to their maximum, and nearly the most efficient value, but will have to run often with 3/4 or 1/2 load with the corresponding loss of efficiency. One may go to the other extreme; install smaller size peaking units with relatively low efficiency but take advantage of the lower installation cost as both factors influence the ultimate cost of the delivered energy. It is very difficult, in fact dangerous, to use rules of thumb in this analysis. The industry has had to resort to the most modern analytical methods to get satisfactory results in the proper balance and timing of various types of generating units.

The location of the units is determined by the relative economics of fuel prices versus transmission cost and such important factors like availability of cooling water, air and water pollution restrictions, and government regulations and public acceptability in case of nuclear plants. Smaller size peaking units (diesel and gas turbine) may be located near load centers but the inherent noise problem can be prohibitive.

We haven't tried to analyze in detail all the factors involved in generation planning, but merely pointed to the most important ones to emphasize the complexity of the problem and the relations to transmission and storage.

Transmission and distribution planning

Transmission planning cannot be separated from generation planning and to a lesser degree even from distribution planning. The roles of transmission are: to carry large blocks of power from the generating stations to the load centers and provide interconnection with neighboring systems; to share reserve capacity and diversity; and to allow interchange of energy on an economic basis. The most economic solution is arrived at when these functions are integrated into one scheme and the individual lines fulfill more than one of these functions. If the problem were only bulk transportation of energy from point to point, other means may prove more economical as Figure 3 shows. These typical data, of course, include the fixed charges as well as operating costs and losses. The data for this chart was taken from a technical committee report of the FPC National Power Survey. Electric transmission is, however, the only means to move energy generated at remote hydroplants.

The capacity of a transmission line, using the same conductors increases proportionally with the voltage while the relative losses decrease. The first planning consideration is, therefore, the voltage to be used for a transmission project. Naturally, at a lower voltage more circuits are needed to carry the same power flow and considering the limitations of right-of-ways and the need to transmit larger and larger amounts of power in the future, it is easy to see why transmission voltages go upward by leaps and bounds to limit the number of circuits and thus the right of way real estate needed.

Figure 4 shows the historical development of highest transmission voltages used in this country. Except for a few experimental lines, at the present time the highest transmission voltage in this country is 345,000 V, but shortly many 500,000 V lines will be operating. 700,000 V transmission will follow in a few years with a large Canadian hydro project. Previously there was not great pressure in this country to raise transmission voltages as most load centers had ample fuel supply nearby. In the meantime, the technology of EHV developed sufficiently and the utilities began to realize that to keep ahead of the increasing demand and keep rates down they have to build larger more efficient units at locations where fuel prices are low. Individual systems are sometimes too small to take full advantage of these developments.

Therefore they have combined their effort to build commonly owned plants and interconnect with neighboring systems and pools by EHV lines.

Another factor plays a significant role for the private utilities; that is competition or potential competition from publicly-owned power suppliers. Sometimes the economic analysis shows no clear-cut advantage for a scheme incorporating extensive EHV. In borderline cases intangibles, such as these competitive considerations, may decide in favor of EHV.

It is obvious that as we increase the voltages of the transmission system we can transmit more power on the right of way and generally we need less number of lines to transmit the same amount of power. Although the outage rate of the higher voltage lines generally is less than the lower voltage lines, the planner has to assume that they would fail occasionally. Therefore, at this point we have to introduce the concept of firm supply. Let us assume, for example, a remote mine mouth plant which for its very nature will be used as base load generation. A single line between this mine mouth plant and the load center obviously cannot be considered firm because even the highest degree of preventive maintenance cannot assure it. To firm up the transmission scheme a second line should be built. The capacity of each line should be at least as much as to be able to carry the full output of the plant during the outage of one of the lines. Therefore, normally the lines will be utilized only partially. Under these conditions too high voltage level with the inherent higher expenditure may be uneconomical at least for the initial operation of the system. Expected later developments such as more generating units at the same location or along the line, or possible interconnections, may justify however the initial higher expenditure to forestall future even higher expenditure. The economic planning of transmission systems is not a series of one shot affairs, but usually involves a coordinated study of as many as 25 to 30 years of developments. The economic solution is what results in the least expensive scheme over the whole period.

Figures 5, 6 and 7 show the cost of point to point transmission of 500 mw at 345 kv, 1000 mw at 500 kv and 2000 mw at 700 kv respectively. Each chart shows three curves reflecting the decrease of transmission cost as the load factor (L. F.), that is the utilization of the line, increased from 50% to 70% and to 85%. These curves were also taken from a technical committee report of the FPC National Power Survey. I would like to emphasize here that these illustrations represent typical values and may not be applicable to a particular situation, where conditions are different from what it was assumed in the FPC survey.

In congested areas the unavailability of rights-of-way, or local opposition, often prevents building overhead lines. Utilities frequently are forced to put the lines underground, which, of course, besides the technical and operating difficulties, involves substantially higher expenditures per circuit mile than overhead lines.

Hitherto we have talked about AC transmission only, but as you probably heard from recent announcements on the west coast two DC-EHV lines will be built together with several AC-EHV lines to bring the surplus hydro energy available in the Pacific Northwest to load centers in the Southwest. These lines will be built partly by private and partly by government agencies and it signifies an unusual cooperation between these two sectors of the electric utility industry in this country. Before we discuss the economics of DC lines versus AC lines, it may be worth pointing out certain important technical differences between them.

First, an AC line by its very nature fits into an existing system without too much difficulty. The power flow on an AC line is inherently determined by the difference of the balance of generation and load at each end of the line, and the equipment and operating methods are well developed. The DC line is an entirely different thing. The energy will continue to be generated and utilized at AC, therefore the power must be rectified to DC at the sending end and converted back to AC at the receiving end of the line. The rectifiers and converters are very expensive equipment especially when we talk about thousands of megawatts and voltages up to 1,000,000 V. The more expensive terminal equipment fortunately is compensated for somewhat by less expensive line design. The losses in a DC transmission line are less than on an AC line because it doesn't have to carry reactive power inherent in the case of an AC line. Operating methods, however, will be more rigid with the DC line involving more intricate control equipment for the whole system. Ignoring special cases, such as underground or underwater cable systems too expensive with AC, or connecting systems with different frequency, DC lines can compete successfully with AC lines only in point to point long distance transmission of very large amounts of power. This restriction of the DC application stems from the relative cost of the terminal equipment and the inflexibility of the DC transmission as far as the future extension of the system is concerned. If along the proposed transmission route important load centers are expected to develop or new generating units will be built, the AC line offers a distinct advantage because it can be more easily tapped according to the requirement. The place of DC lines, at least at the moment, is in clear-cut long distance point to point transmission, or in the special cases of underground or underwater transmission mentioned.

Figures 8 and 9 compare the cost of point to point transmission by AC versus DC for a "typical" case. The cost figures include the cost of the terminal facilities too.

Distribution

We pointed out earlier that the economics of the distribution can stand on its own feet, largely independent of the economic considerations in associated generation and transmission. Distribution systems are as varied as the areas they supply. A distribution system in a rural area has different problems than a densely populated urban area. It is of course more economical to locate the distribution substation somewhere near the center of the area it serves, but frequently it is not possible and the utility has to consider alternative locations. It is increasingly difficult to acquire property in densely populated areas because of zoning problems or because property is simply not available.

The location of the substations is one of the most important economic factors in the distribution system as it determines the length of the feeders from the station to the customer. Just like in the case of generation and transmission it is not sufficient to solve the immediate problem, but the future load growth has to be taken into consideration. Later, more and more substations will be needed and the system should be so designed as to make it easy to affect future extensions and changes. Sometimes substation property must be acquired well in advance of the actual need to assure its availability.

The quality of electric service is measured by its reliability, and by tightness of voltage and frequency regulations at the point of delivery. Except for frequency, most troubles originate in the distribution system. It is more vulnerable to adverse outside influences, such as weather, than the transmission system.

Rapidly increasing customer loads coupled with the previously mentioned factors has resulted in an upward push in distribution voltages. Recently utilities have decided to build underground systems to improve the appearance of the community and at the same time the reliability of service. These tendencies naturally resulted in increased cost of the distribution system. An underground distribution system still costs much more than an equivalent overhead system. The utilities are making a great effort to keep this cost down by constantly improving the methods and equipment.

Pumped storage

We have been asked to talk about storing energy and, as mentioned before, it cannot be stored economically in the form of electricity. Early in this presentation when we discussed the operation of a system we pointed out that the cost of total energy at any given moment depends upon the generating units providing it. As the load increases on a system at a given day, more and more units are put into service with lower efficiency and higher operating cost. If we can devise some means whereby we can store energy produced at a low cost and release it at a time of high demand and high cost, we may justify the expenditure for that storage.

The operation of a pumped storage plant is simply to pump water from a lower reservoir to a higher one during light load periods on the power system when only efficient units operate, usually at night and weekends, and release the water to generate energy during heavy demand when otherwise inefficient units would have to be operated.

Pumped storage plants, utilizing this concept, have gained popularity in this country. The concept was known for many years but in this country it had not been popular until the economic reversible pump-turbine was developed some years ago, which made it possible to lower installation costs. Before, each unit consisted of a generator-motor and a separate pump and turbine, all on the same shaft.

Naturally, the pumping-generating cycle involves losses and at the present such plants operate at about 66% cycle efficiency; that is, only 2/3 of the energy used to pump the water to the upper reservoir can be regained when generating. What makes then such a plant economic for a utility? We have to look again at the daily load characteristics of a system and the available generating units to meet the load most economically. We have talked about it briefly, but to understand the economics of pumped storage we have to look into the subject in more detail.

The generating system consists of many units, some of them large efficient base load units, some older less efficient units, once themselves base load units, which are normally shut down during light load periods, and peaking units used only during the heaviest demand period. The relative balance of these units varies with each system. If the system has a relatively high proportion of efficient units, these may have to be curtailed during light load periods with the resulting loss of efficiency. It may even be necessary to shut down some of them frequently, thus incurring extra cost for start-ups and subjecting them to incremental maintenance. With such a system, the pumped-storage should be investigated as a means to provide peaking capacity provided, of course, that a suitably economical site is available for such a development at a reasonable distance. The operation of the system then would be that during light load the efficient steam units, which otherwise would be partly loaded or shut down, would provide the pumping energy at a relatively low cost, thus filling the valleys of the load curve. During heavy demand the pumped storage plant would provide the peaking energy at a lower cost than alternative peaking units could. Figure 10 shows the daily load curve of a system with pumped storage. As you can see the base load units are fully loaded throughout the day. When the actual load drops below the capacity of the base load units during the night, the difference is used for pumping. During peak hours the pumped storage plant generates instead of other more expensive types of peaking units.

For example, let us assume that the base load units provide the pumping energy at 2 mills per kwh, then the cost of energy generated at the pump-storage plant will be 3 mills per kwh because of the losses in the cycle. This 3 mills per kwh figure then should be compared with the energy cost of other types of peaking to determine which one is more economical.

The installation cost of the pumped storage plant and the alternative peaking plants, and the operating cost of the whole system with and without the pumped storage must be very carefully analyzed to determine the economic solution. In this case just as any other problem, not only the present condition should be looked into but also how it affects future economies. The investigation also involves the analysis of the optimum size of the reservoirs at the pumped storage plant.

Naturally, the installation cost and the optimum size of the reservoir are largely determined by the local topographical and geological conditions at the site, which is beyond the control of the utility.

The geographical location of the prospective pumped storage plant, as related to load centers and generating stations providing the pumping energy is another important factor. The transmission lines leading to the pumped storage plant have to connect the plant with load centers and transmit pumping power from other generating sources. The problems are, therefore, somewhat more complex than with conventional hydro or steam stations and require detailed investigation and in the final analysis it may be decisive for or against the pumped storage plant. Several other factors can influence the economics of a pumped storage plant besides those just mentioned; such as the sharpness of the peak load period, that is its magnitude and duration, and the amount of excess cheap energy available for pumping during off peak periods. Obviously a system with sharp peaks will find a pumped storage plant more attractive than another system with flat peak periods and relatively cheap peaking energy already available from conventional hydro plants.

Expected future developments

We have discussed a few of the current problems of storing and transmitting electric energy. Now, based on the present conditions and trends, we can make a reasonable projection into the future.

The electric utility industry is facing a tremendous task. The load has been increasing at such a rate that it doubles every ten years. We can foresee no saturation in this respect and plans are based on the assumption that this trend will continue in the foreseeable future. This pressure of increasing load will inevitably force utilities to combine the efforts and form more interconnections and power pools. These pools in turn will make it possible to build larger and larger units. Individual systems of moderate size cannot hope to build these units, because of the penalty they have to suffer as a result, in the form of increased reserve requirement. But as a member of a larger group they can enjoy the full benefits, as the installation cost per kw decreases with the size. The overall reserve requirements will be less and operating costs are expected to decrease also. Naturally, these large size units will be built where fuel prices are advantageous. As gas and oil prices are increasing there is a revival in the interest of coal in areas where coal has not been used, for example in the Southwestern part of the country. Elsewhere in the country, the coal transportation costs are decreasing, which has an important influence on this revival of coal. This development and the EHV transmission makes it possible for the industry to maintain a healthy economic status and at the same time decrease energy cost and provide more reliable service.

In the field of transmission we expect the voltages to go up to 1, 000, 000 V, which is technically feasible even today. Beyond this it is difficult to make predictions.

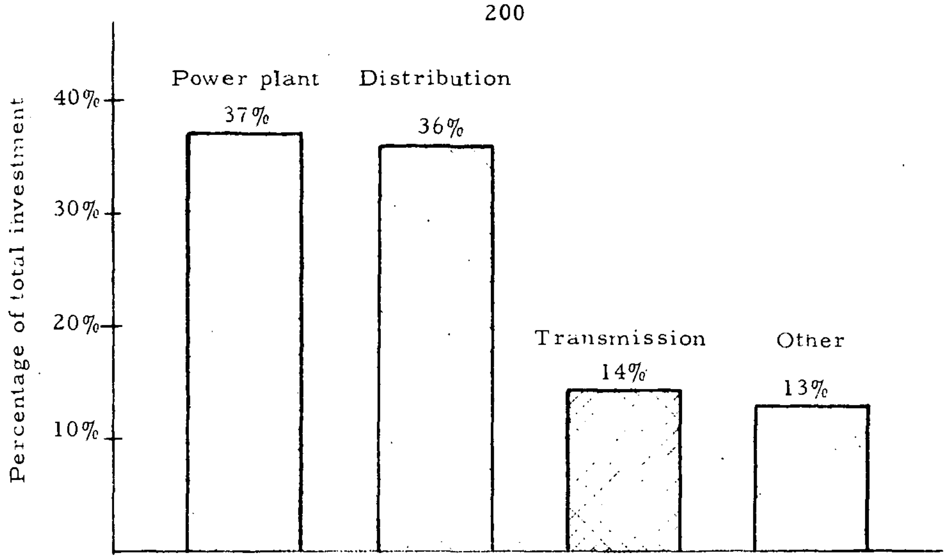
The relative share of hydro energy is going to decrease as economic sites are being rapidly developed in this country. There are huge hydro resources available in Canada however. In spite of this, it is expected that such regions as the Northwest, which hitherto has relied exclusively upon hydro power, will have to resort to other sources for energy in the not too distant future.

The relative share of nuclear energy in the future is still being debated. There is a general agreement that it can compete in areas of high fuel cost but recent announcements (Oyster Creek) indicate that it has a chance to compete in relatively low fuel cost areas, such as the Midatlantic states. Unquestionably nuclear energy will be used more and more.

We heard a lot of talk about various methods of direct conversion recently. All of these projects are in experimental stages and it is difficult to estimate their future influence. Only the MHD method appears to be economical in large size central stations at this time. Significant development, either economical or technological, can materially change the economic picture of future energy delivery.

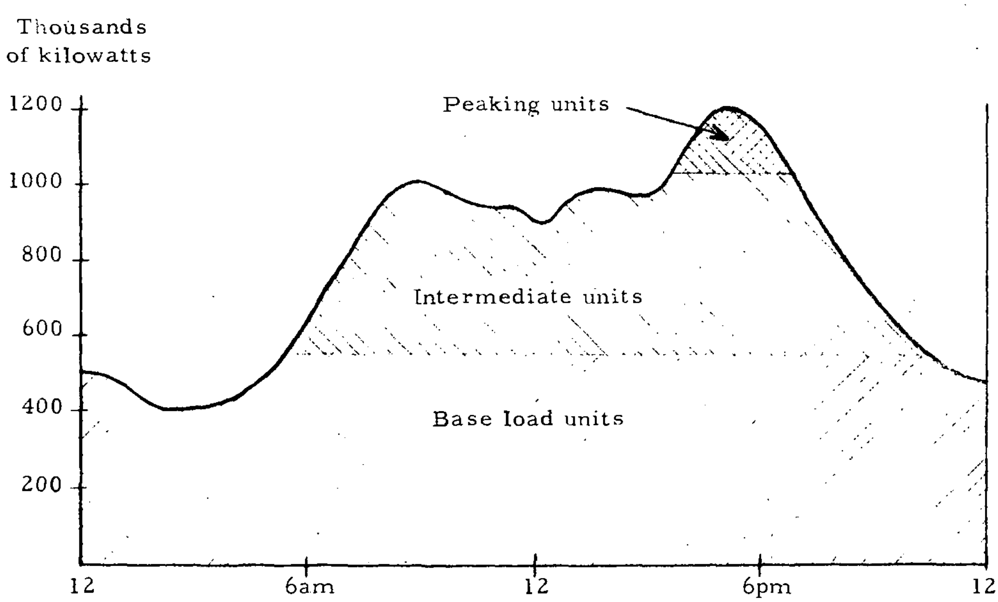
The electric utility industry, contrary to the popular belief, is not without vigorous competition with other types of fuels. They are vigorously campaigning to increase their load and one of the brightest areas in their competitive picture appears to be electric space heating. Their approach of promoting load growth and thereby decreasing the cost of supply, assures that electricity will continue its strong technological and economic development well into the future.

The speaker wishes to express appreciation to Mr. Zoltan Csukonyi of the Bechtel Corporation for his invaluable work in the preparation of this paper.



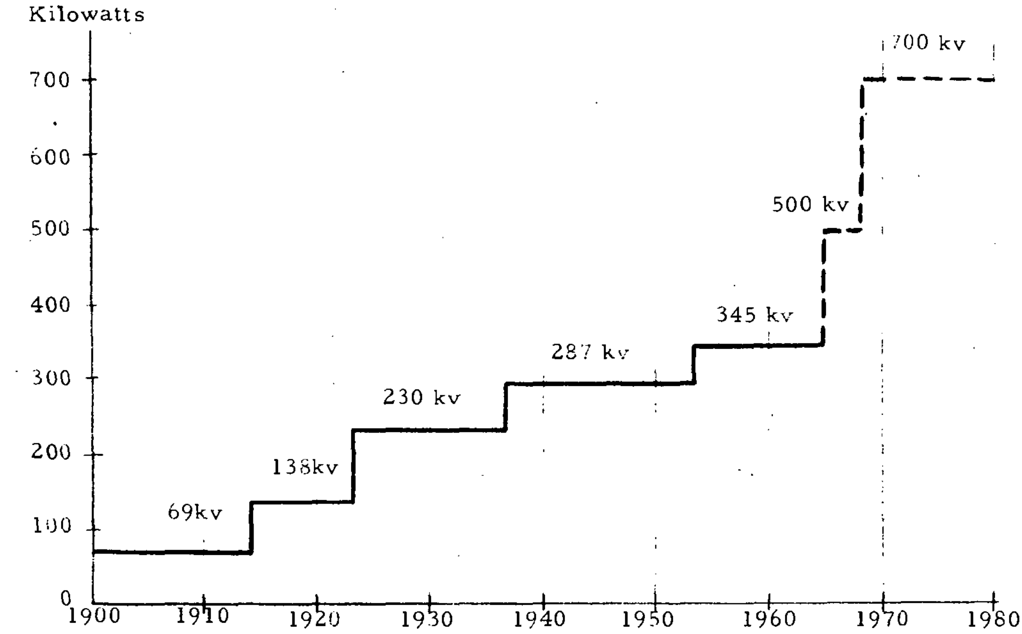
INVESTED CAPITAL STRUCTURE OF AN ELECTRIC UTILITY

FIGURE 1

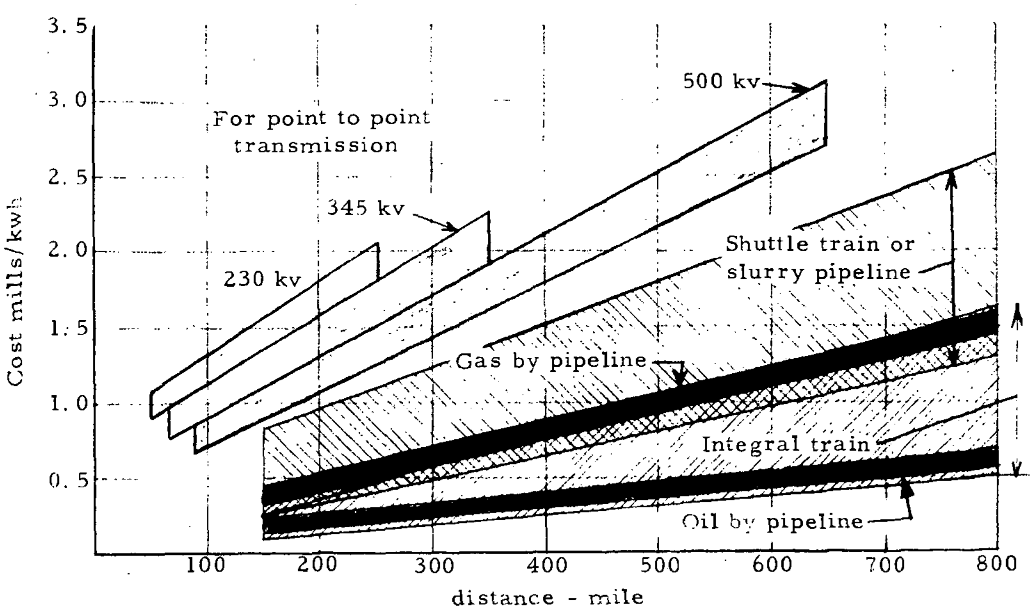


TYPICAL DAILY LOAD CURVE OF AN ELECTRIC SYSTEM (Winter Day)

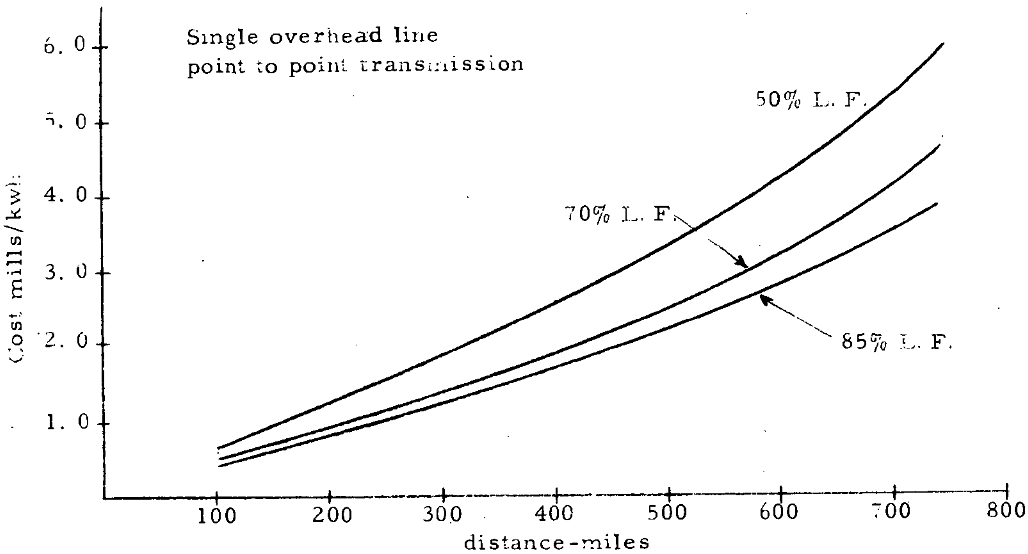
FIGURE 2



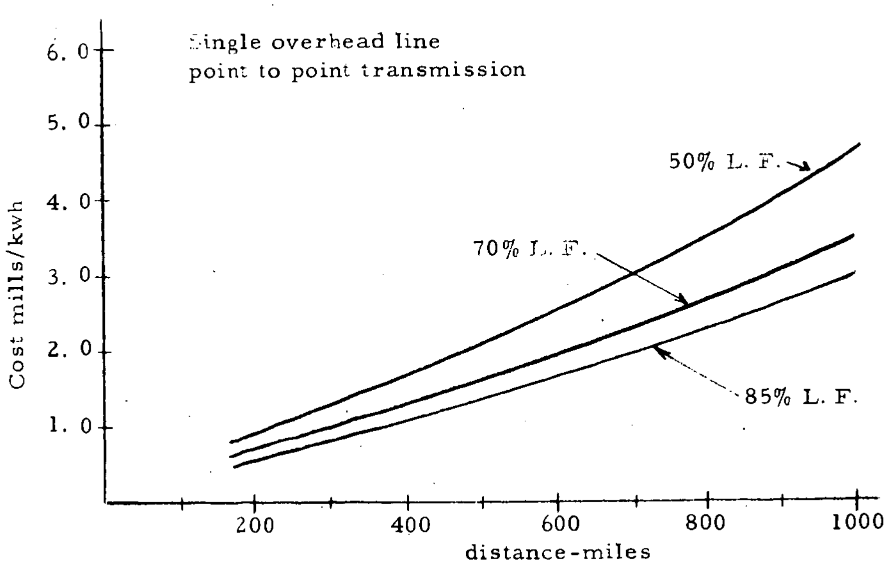
HISTORY OF HIGH VOLTAGE TRANSMISSION FIGURE 4



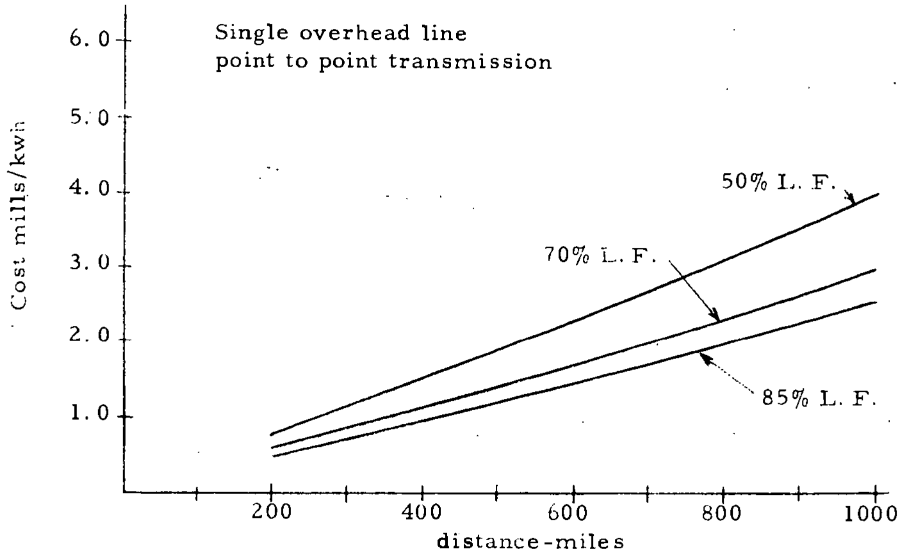
TYPICAL POINT TO POINT
ENERGY TRANSPORTATION COSTS FIGURE 3



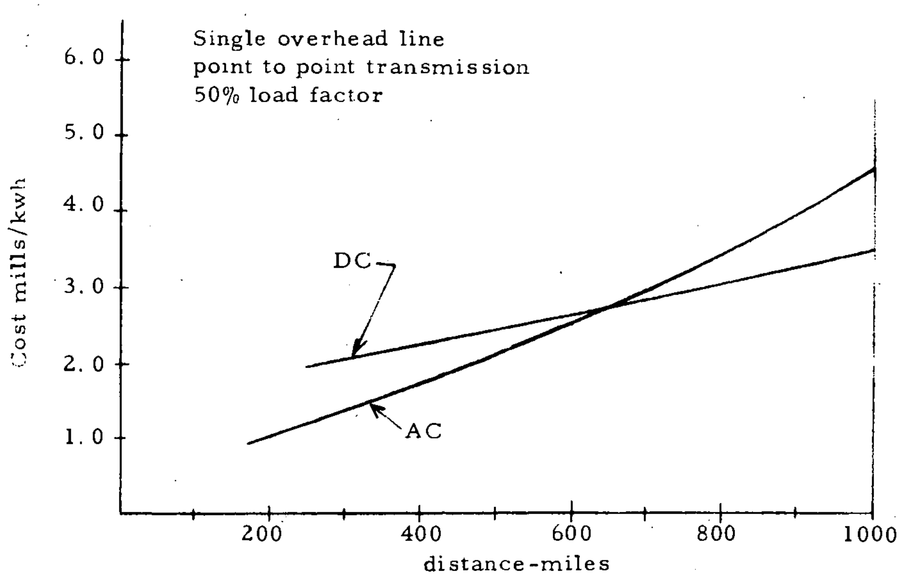
TYPICAL TRANSMISSION COST 345 KV-AC 500 MW FIGURE 5



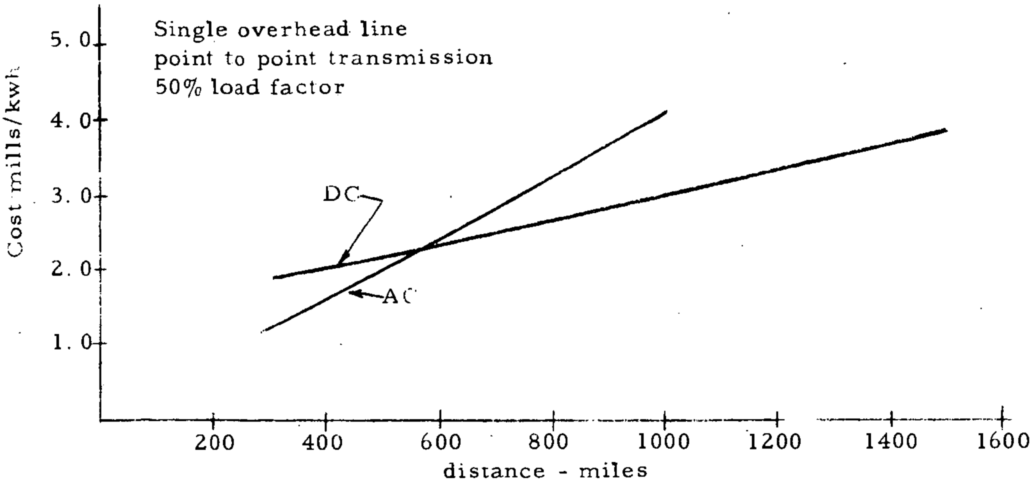
TYPICAL TRANSMISSION COST 500 KV-AC 1000 MW FIGURE 6



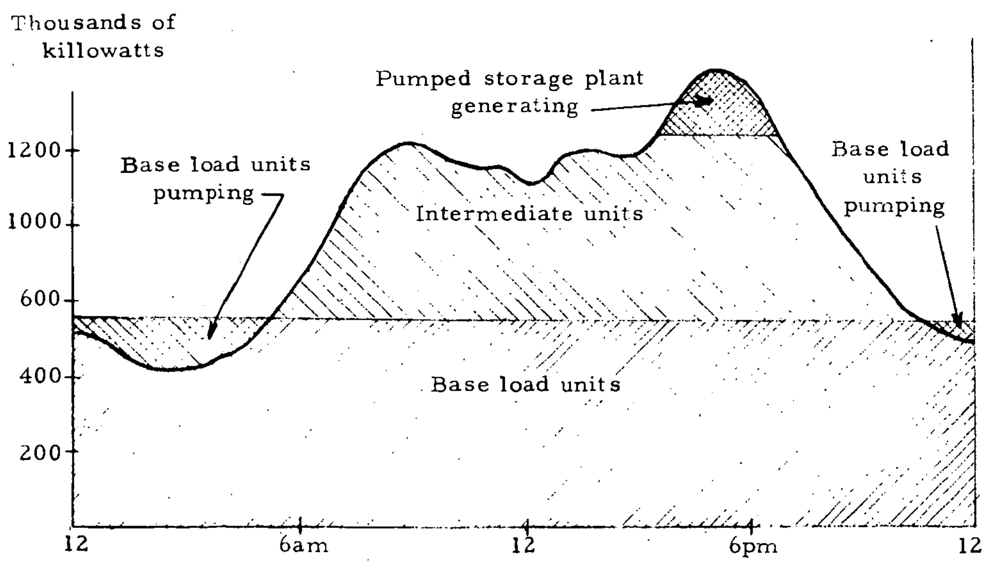
TYPICAL TRANSMISSION COST 700 KV-AC 2000 MW FIGURE 7



TYPICAL AC & DC TRANSMISSION COST COMPARISON
500 KV-AC vs ± 375 KV-DC 1000 MW FIGURE 8



TYPICAL AC & DC TRANSMISSION COST COMPARISON
700 KV AC vs $\pm$ 500 KV DC 2000 MW FIGURE 9



DAILY LOAD CURVE OF AN ELECTRIC SYSTEM
WITH PUMPED STORAGE FIGURE 10